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THE REPLACEMENT OF HISTORIC ORNAMENT WITH
FIBERGLASS REPRODUCTIONS
IS IT A REALISTIC ALTERNATIVE?

Jill Avra Hittleman

A THESIS

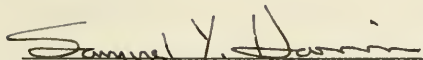
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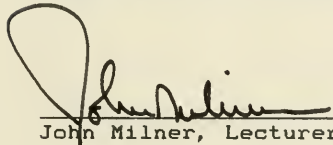
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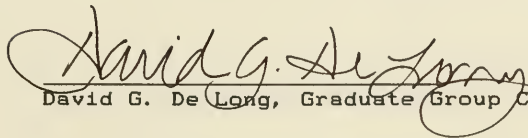
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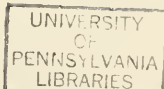
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INTRODUCTION

Over the last twenty years interest in historic preservation in the United States has grown dramatically. The increasing awareness of the value of our cultural past and the economic feasibility of re-using existing structures has resulted in the rapid expansion of building conservation. With the upsurge in neighborhood rejuvenation and low budget redevelopment projects there has been an intensifying need for inexpensive conservation techniques.

The search for a solution to this problem has resulted in research and technical developments in the use of substitute materials for replacement of deteriorated or missing historic ornament.

The goal of this study is to offer substitute materials, particularly fiberglass, as a solution to many difficult conservation problems. Although this study discusses fiberglass, the guidelines for its evaluation and selection apply to all substitute materials.

Chapter one will review the history and development of fiberglass. Chapter two will look at the difficult questions that face conservationists. Case studies will be used to define current problems of building conservation, specifically the restitution of components where replacement "in kind" is not feasible. Chapters three and four

will investigate the composition and fabrication of fiberglass to explore the nature of the material and its inherent and resulting properties. Chapter five will examine the weathering of fiberglass and its ability to perform visually, physically and mechanically over time. Lastly, Chapter six will evaluate the durability and compatibility of fiberglass and its success or failure as a solution to current conservation problems.

CHAPTER 1 - THE HISTORY OF FIBERGLASS

The invention of glass fiber as reinforcement can be attributed to the handiwork of nature which came to be known as "Pele's Hair." Pele's Hair came about as the result of powerful winds sweeping across vitreous volcanic dross during a lava flow. The lava as a fine fibrous mass was transported by the wind and deposited in trees. The leaves of these trees, coated with the fibrous lava mass, were then used by birds as reinforcement in the building of their nests.¹

In ancient Syria, Greece, and Egypt, before the invention of the blow pipe in 250 B.C., glass artisans drew fibers from a heated glass rod. These fibers, while in a fluid state, were impressed onto the surfaces of ready-made objects. They were either left in place to harden or reheated and tooled to form decorative patterns on their glassware.²

Craftsmanship with molten glass fibers was common among the Phoenicians and Venetians. In the 16th and 17th centuries the Venetian glass makers of Merano made finely decorated, thin-walled "lace" glass stemware.³ During the same period the Romans produced millifiori glass. In the late 17th and early 18th centuries the English, French and German glass manufacturers fashioned methods for drawing fine glass threads from small hot melts and heated glass

The history of the United States is a story of a people who have grown from a small colony of English settlers to a great nation of free men and women. The story begins in 1492, when Christopher Columbus discovered the New World. The first English settlers came to the Americas in 1607, and the first American-born child was born in 1609. The story continues through the years of struggle and growth, from the American Revolution to the present day. The United States has been a land of opportunity and freedom, where people have come from all over the world to seek a better life. The story of the United States is a story of hope and achievement, of a people who have built a great nation out of a small colony.

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rods. By 1832 they had mechanized the system and were drawing glass threads of an indefinite length from a hot melt onto a revolving wheel. The glass thread was woven into sheets of fabric with other textile materials or used for embellishment on otherwise ordinary objects.⁴

Techniques for reinforcing have been used by man since the days of the early Egyptians with the incorporation of straw into bricks. However, the science of glass fiber reinforced plastics is basically a late 19th and 20th century phenomena. "The amalgamation of a strong but friable reinforcing material with a weak but adhesive resinous matrix was conceived in antiquity, but brought into today's focus by modern materials and processing technology."⁵

Entrepreneur Edward Drummond Libbey and his accomplished assistant Michael J. Owens used fine spun glass fibers to make a dress and neckties for the 1893 Chicago exhibition. The show sparked interest in the potential of glass fibers. In 1927 research was initiated by Owens Illinois and Corning Glass Works. During the 1930's Ford joined with Libbey and Owens in a venture to form a glare-reducing panel by laminating colored glass fibers between sheets of flat window glass. Although these undertakings were triumphant the potential of glass fibers still remained untapped.⁶

The Owens-Corning Fiberglas (fiberglas with one 's' is a trade name of Owens-Corning) Corporation was incorpo-

rated on November 1, 1938 after 10 years of joint research between the two companies.' A research program, based at Purdue University in Ohio, was initiated to find methods to mechanize the production of glass fibers. The results were successful. Advanced technology was developed for the fabrication of all three glass fiber types; continuous filament, staple fiber, and wool or blown glass fibers. The first products of each method were; blown "white wool" insulation, coarse staple fiber air-filters, and fabric woven from continuous filaments. The glass fiber fabric was impregnated with resin and used for encasing electrical equipment.⁸

The development of polyester resin paralleled that of glass fibers. Dr. Leo H. Baekeland conducted experiments with phenol-aldehyde reactions from 1905 to 1909. Dr. Baekeland did not invent the phenol-formaldehyde reaction but was the first to make it usable. He knew that when phenol and formaldehyde were combined they would go through a condensation reaction. When heat was added to this reaction it would cause the mixture to harden into an insoluble resin. However, this product was not usable in and of itself. Dr. Baekeland discovered a way to use catalysts to slow down the setting process, therefore allowing the addition of reinforcement to the resin.⁹ In 1933, Carlton Ellis patented unsaturated polyester resins and in the following years the resin industry boomed.

With the incorporation of The Society of Plastic

Industry (SPI), in 1937, the reinforced plastics industry was at last off the ground.¹⁰ The Reinforced Plastics/Composites Division of The Society of Plastics Industry has been essential to the development and progress of the reinforced plastics industry. When originally organized, this division was called the Low Pressure Industry Division. In 1951 the name of this division was changed to Reinforced Plastics. The name was changed again in 1967 to the present name, Reinforced Plastics/Composites, since the division began to work with other composite materials besides glass fiber reinforced plastics.¹¹

World War II was a 'feather in the cap' for the glass fiber reinforcing industry. Needs created by World War II required major research and development programs to study materials, manufacture and design of glass fiber reinforced plastic (GFRP). As a result, there were successful applications of molded and laminated products. Attention was focused on the development of molding methods for low-pressure curing resins and glass fiber reinforcement.¹²

The need for nonmetallic, nonconductive and non-corrosive materials during the 1940's triggered concentrated research to examine the potential of glass fiber reinforced plastic. "Military and Industry researchers solved the problem by using the historic first volume use of fiberglass RP [Reinforced Plastic] with polyester resins, then known as low-pressure and vacuum-pressure laminates."¹³ Other initial reinforced plastic end

products were puncture-proof noncorrosive gas tanks, electrical equipment, flack-suit body armor, plastic seats, and other non-metallic weight-reducing components for military aircraft, ships, automobiles, and personnel.''

After the war, it was important to adapt glass fiber reinforced plastic to domestic production. Owens-Corning Fiberglas Corporation assembled a road show to familiarize the public with the potentials of glass fiber reinforced plastic. The show exemplified every imaginable use for fiberglass. "The thermal performance was aptly shown by wrapping a frozen one-quart ice cream package in a fiber glass insulation blanket, and subjecting it to the heat of a baking oven in the same compartment with a pie being baked. At the conclusion of the baking time required for the pie, both were removed from the oven, and pie a la mode served, the ice cream still being in the frozen state when unwrapped."'

The other properties of fiberglass were displayed in similarly humorous fashions. Owens-Corning Corporation gave licenses to several domestic and foreign firms to produce GFRP. Competition among manufacturers sparked research and development. "An example of progress occurred when General Motors introduced the RP body on the Corvette in 1953 after numerous automotive parts had been produced in experimental lots some five to ten years earlier. Truck fenders for replacement purposes were fabricated in molds made from existing metal fenders when production molds were

no longer available."¹⁶ In the 1960's one of the first commercially important architectural glass fiber reinforced plastic units was produced. A protective layer was applied to a previously invented GFRP cladding rendering it more chemically resistant.¹⁷

As fabrication processes were refined, the mold costs, raw materials, and production time were reduced. New machinery was developed that allowed for fully automated continuous production. Fabrication processes now include; hand lay-up, spray-up, vacuum bag, pressure bag, autoclave, filament winding, centrifugal casting, continuous pultrusion, matched-die molding, injection molding, and continuous laminating.¹⁸

Glass fiber reinforced plastic with its low cost and light weight became increasingly popular in creating unique decorative and utilitarian objects. The rivalry for success among GFRP producers provided the impetus for the 1965 upsurge in innovation and productivity which has continued to the present.¹⁹

During World War II, the prices of glass fiber reinforced plastic products were extremely high. This can be attributed to the newness and inefficiency of the manufacturing processes and the importance of fiberglass as a military material. With the end of the war, the intense necessity for fiberglass was eliminated and the prices dropped and continued downward until a period of renewed interest caused an upsurge between 1960 and 1965. From

1965 to the present, prices have increased at a fairly steady rate because of typical inflationary influences. Prices, however, still remain relatively low. "In order to keep up with inflationary trends, prices have been kept down by eliminating process steps and making labor and material-saving combinations of glass, resin, and filler. Attempts have been made to formulate glass-resin molding compounds by incorporating fibers at the glass forming operation directly into the polymeric matrix."²⁰

Today, manufacturers are producing over 1 billion lbs. of glass fiber reinforced plastic products annually. Glass fiber reinforced plastic skins have been wrapped over wood, plywood, masonite, and rigid foam substrates for a variety of industrial and domestic uses. Glass fiber reinforced plastic has been used as both a noncorrosive layer and a nonshattering shell over glass and metal units that would otherwise be unusable. The uses of fiberglass to date are innumerable.²¹

Advancements in technology have resulted in glasses and resins with various properties to fit specific design constraints including; greater chemical durability, greater strength, higher modulus of elasticity, and increased fire resistance. Improvements in molding technology have enabled fiberglass manufacturers to produce: structural elements for buildings in hostile atmospheres; molded automobile and airplane components that are lighter in weight and far less expensive than similar metal components;

marine vessels that offer lighter weight, greater strength and reduced maintenance than earlier commercial vessels; and many useful and ornate building components including shower stalls, windows, cladding, and decorative ornament.* *

In architecture and preservation, glass fiber reinforced plastic is becoming increasingly popular to replace more conventional building materials such as stone, metals, wood and terra cotta. Specifically in preservation, fiberglass is being used as a replacement material for light posts, sculptures, cornices, roof tiles, details and full facades.

The continuous increase in the popularity and consumption of glass fiber reinforced plastics indicates its increasing value as a competitive engineering material. Advancing technology has left the door to the future of glass fiber reinforced plastics wide open. The possible future applications for this product are innumerable.

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CHAPTER 2 - THE PROBLEM AND THE FIBERGLASS DECISION

One of the major problems that faces owners, developers and architects/conservationists is the stabilization, replication, or replacement of decorative building components. These features are the principal architectural elements in identifying the character of the building or buildings. With the deterioration or removal of these pieces, design unity and richness of detail are lost. The problem is not only visual but technical as well. New solutions can exacerbate the problem or create new problems of their own.

"Building conservation implies that there is change. Sometimes that change can be unnoticeable, the results of careful efforts to slow the natural weathering and decomposition of materials through repainting and repointing, cleaning and general repairs."¹ Unfortunately, most buildings approached by conservationists have undergone many years of vandalism and neglect and building components are no longer in a condition to provide a minimalist approach to conservation. The damage has often exceeded the capabilities of simple maintenance or repair, and the process of building conservation results in more significant modifications.²

Most often, the deteriorated building features are comprised of wood, metal or terra cotta and are located in

positions susceptible to the greatest environmental abuse. Regions that are typically the most vulnerable are; siding or cladding, porches, bays and turrets, roofing and roof structures, window and door trim, and architectural ornament especially fascias and cornices.³

The results of conservation efforts can be adversely affected by the inavailability of properly designed, manufactured, and installed replacement units. When replacing a historic material the National Park Service Standards for Rehabilitation request replacement to be "in kind". This means to replace a building component with the same material as the original, and where possible, tool and install in the same fashion. Often, however, this solution is not be feasible and alternatives must be considered.⁴

There are innumerable conservation projects where substitute materials must be considered. The following case studies are examples where consideration of substitute materials led to a "fiberglass decision". The purpose of this section is to give a history of the case structures illustrating the significance of the elements to be replaced and the project constraints placed on the architect/conservationist. A discussion of the "fiberglass decision" highlighting the requirements of a substitute material will follow the case histories. Throughout the remaining technical chapters reference will be made to these three case studies as typical examples.

SMYTHE STORE CONDOMINIUMS

The Smythe Store Condominiums are located on the north side of Arch Street between First and Second Streets in Philadelphia's Old City Historic District. The row of cast iron buildings located close to the Delaware River were built to be used as warehouses for the trade industry. During the time of their construction, c.1885, cast iron was gaining popularity as a building material. Cast iron allowed for the production of ornately designed elements for common use buildings. It proved to be quick and economical when used to form repetitive building components. The Smythe Stores, a row of five identical facades with five floors of repeating components, was an ideal situation for the implementation of this new construction technique (see illustration 1).⁵

The Smythe Stores, designed in what has been called a "Northern Renaissance" style, was developed by Samuel Smythe. In the "Historic Preservation Evaluation of Significance", prepared for the United States Department of the Interior, the craftsmanship of the cast iron facade is credited to Tiffany and Bottom, although the design is said to have been the work of H.C. Oram and Company.⁶ As it stood in 1855, the Smythe Stores complex was a handsome commercial row. The historical significance "lies in both its singular architectural importance as one of the richer commercial fronts in Old City, and as an integral part of the fabric of Philadelphia's important mid- and late- 19th

century commercial and warehouse district."⁷ The facade was designed on a six bay modulus neatly tied together with a continuous ornate frieze and even more complex cornice. The classical columns, intermediate cornices, arched window openings, and decorative ornament clearly display the capabilities of the newly developed casting technique (see illustration 2).

In 1907, one of the five buildings was demolished to allow for the expansion of Philadelphia's trolley system. Then in 1920 the buildings suffered further damage with the removal of the original cornice. As the trade industry along the Delaware declined, the need for these warehouse buildings diminished, and little by little the Smythe Store row was abandoned. The vacant buildings were targets for vagrants and vandals, while the unmaintained cast iron facade was exposed to harsh weathering conditions.*

In 1975 the fate of the Smythe Stores worsened. The end building in the row was dismantled to allow for the construction of highway I-95. Because of the value of this historic row, the cast iron facade was carefully dismantled and buried for safekeeping in Philadelphia's Fairmount Park. Sometime around 1977, the trolley tracks were abandoned and the property converted into a parking lot.*

With the declaration of Old City as a historic district, the interest in the Smythe Store buildings was renewed. In 1982 the Smythe Store Associates purchased the row intending to convert them into condominiums. There was

a need for major repair to allow for the building's rejuvenation. The Smythe Store Associates decided to fill in the vacant parking lot with the cast iron facade that was supposedly preserved, once again completing the row. However, after a lengthy search it became clear that the original pieces of cast iron were missing.¹⁰

The problem then became how to reconstruct the missing facade to match the remaining historic structures. Cast iron which was once used for its economic feasibility was no longer economically feasible. It therefore became clear that a substitute material was necessary, and fiberglass was chosen.

THE LANSDOWNE APARTMENTS

The Lansdowne apartment complex is located on the corner of 41st street and Parkside in West Philadelphia. The Parkside neighborhood, near Memorial Hall in Fairmount Park, is a neighborhood that was founded by German immigrants and flourished with the arrival of the 1876 Centennial.¹¹

The Lansdowne Apartments were designed c.1885 to correspond to an irregular site. The complex sports an extravaganza of decorative elements, towers, turrets, bays and gables, which appear to challenge any logical plan or pattern (see illustration 3). Pressed metal work of galvanized iron was employed for the ornamental cornice and bay work. This material, fairly inexpensive at the time,

was appropriate given its ability to take on a diversity of forms and ornamental patterns.¹²

As the neighborhood deteriorated the building fell into disrepair. Once vacated the building was completely neglected and deterioration was rapid.

In 1967 Jim Brown, then a young medical researcher and now the developer of the Parkside rejuvenation project, and William Henderson discovered the abandoned 19th century building. Aware of the depressed state of most of the historic fabric in the neighborhood they boarded up the doors and windows in an attempt to save the Lansdowne from further destruction. A few months later the Lansdowne Apartment complex appeared at an auction. Jim Brown and William Henderson were the high bidders and found they had a severely deteriorated yet potential gem on their hands.¹³

By 1972 the exterior of Lansdowne had been stabilized and the interior rehabilitated providing nineteen units for a mix of middle income and section eight rent subsidized apartments. In 1982 the apartment complex was given Landmark certification allowing Jim Brown to make use of tax credits and facade easements to restore the ornate facade.¹⁴

The major problem in the Lansdowne facade conservation was the repair or replacement of all the ornamental work. The cornice and towers with their elaborate decorative patterning were essential instruments for expressing the architectural style (see illustrations 4 and 5). The

cornice, being in a vulnerable location at the juncture of the roof and wall, exposed to the weather, and subject to considerable moisture had suffered the greatest deterioration.¹⁵

The Lansdowne's galvanized iron cornice was over 100 years old. Therefore, corrosion or decay would not have been surprising even if it had been well maintained. However, since the cornice had been severely neglected it was deteriorated beyond repair. This resulted in a need for conservation strategies which would go beyond maintenance or simple repair.¹⁶

Once replacement was determined the predictable question of, "With what?" became the object of much confusion. Since the galvanized iron seemed essential to the quality of ornament, replacing it in kind was seriously considered. Unfortunately the costs of the material, craftsmanship and accurate duplication was not feasible for the project's budget.

The problem once again became how to duplicate the deteriorated and missing ornament to match the remaining historic fabric. It was obvious that a substitute material was necessary and fiberglass proved to be the best choice.

GEORGETOWN UNIVERSITY STUDENT HOUSING

The Georgetown University Student Housing project is located on 37th street between N and O streets in Georgetown. Designed by Hugh Newell Jacobson in 1984, the

project had to address the scale and character of Georgetown's neighborhoods filled with mostly small residences and townhouses (see illustration 6).¹⁷

The building's general plan is a U shape with its long side facing 37th street. This long side is broken down into townhouse like units with stair-entries to recall that of the surrounding buildings. The building height of three stories was retained on the street facade by steeply sloping the site and creating English basements. Even where the neighboring buildings reduce in height to two stories the dormitories do not appear obtrusive.¹⁸

The building's facade is a rather simple federal style brick facade capped with a deep, decorative cornice terminated by accent brackets at the corners (see illustration 7). The rather plain facade is interrupted at the ends of the block by ornate Italianate oriels which bring light into the stairwells. The building's stair rails are wrought iron and patterned in a manner typical to historical Washington. In fact they were designed to imitate an original piece of a historic rail found at a junkyard. To further develop historic compatibility, the building was designed with copper scupper boxes only deviating from what would be historically expected by the embossed GU's.¹⁹

Concern for the historic quality of the neighborhood was obvious throughout the project. Given the objectives of continuity and harmony, the problem was how to economically imitate the elaborate cornices of the surrounding

buildings for use on a building over ten times their size. Once again, the decision was to use fiberglass.

THE DECISION

As mentioned earlier, the priority of the architect/conservationist on the job may be to restore the original material in kind. The owner or developer, however, may have other priorities including time and expense. When the original material or craftsmanship are unavailable or costs are too high, a substitute material is often the best solution. When choosing a substitute material it is essential to consider aspects of visual, physical and functional compatibility.

The replacement material should match the original material in color, texture, reflectance, profile, size, scale and rhythm. This is especially important in replication of historic components such as the Smythe Store Condominium facade and the Lansdowne cornice, where the new material directly abuts existing historic fabric (see illustration 8).²⁰

The porosity and absorption properties of a material can alter the color and reflectance of the end product when wet. It is therefore essential to check the substitute material's color and reflectance when wet and dry. Some substitute materials will be indistinguishable from the original material on a sunny day, but will be a vivid mismatch on a rainy day. In cases where the substitute

material is high above the street level view, or where the material is to be painted, there is greater flexibility in the match of materials.²¹

For non-structural replacement, the strength and weight of the substitute material should be equal to or less than that of the original material and surrounding historic fabric. The substitute material as the sacrifice component eliminates the chance of damage to abutting historic components as a result of excessive pressure from the substitute material. This recommendation also insures that the new loading will not be too much for the original structural members to support.²²

If the substitute material is used as a filler between existing pieces of ornament, it is essential that the coefficient of expansion and contraction of the substitute material be close to that of the original material. If it is greater, the new material may put stress on and damage surrounding components. Expansion stress from saturation swelling is another stress related concern. The porosity and rate of hygroscopic absorption of a substitute material should be compatible with the original and surrounding materials. Swelling of the substitute material can once again put excessive pressure on the remaining historic fabric.²³

The chemical composition of the substitute material must be similar to or compatible with the remaining historic fabric. Even very small amounts of acids, salts or

alkalines could cause corrosion or decomposition to adjacent and lower historic materials. This is especially true during rain storms when water can carry the acids, salts or alkalines of one material across the facade to other materials.

The substitute material must perform as well as the original. This means that the substitute material must be as durable as the original material to be cost effective. If the substitute material has a shorter life span than the original material repetitive installation labor costs must be added into the overall cost estimate. In cases where installation costs are high the substitute material will not be cost effective in long term planning. However, due to the rapid turn-over of buildings in our society many owners refuse to consider long term costs and choose a substitute material with the lowest initial cost. The weathering and maintenance of the original and substitute material should be compatible. The substitute material should not require more frequent maintenance than the original material or the building will usually suffer neglect.²⁴

For The Lansdowne apartments and The Smythe Store Condominiums the cost to replace in kind were exorbitant. The historic nature of the projects determined visual replication to be a priority. Cost, however, even if only short term, was a controlling factor.²⁵ Fiberglass was the only material that could accurately reproduce the original

details and stay within the project's budgets. Therefore, based on aesthetics and cost all other substitute materials were eliminated as alternatives.

Fiberglass offered the opportunity for casting directly from the existing historic fabric, thus producing an accurate replica (see illustration 9). When possible building components were disassembled to allow for mold fabrication in the shop. However, when necessary, molds were cast on the site. Fiberglass offered the option of various fabrication techniques.²⁶ It was light in weight, easy to install and relatively low in initial cost when compared to other alternatives such as sheet metal, cast stone and wood. Thus the decision was glass fiber reinforced plastic.

In the case of Georgetown University Student Housing the historic fabric was not a factor. Wood was considered as a possibility to match the surrounding wood cornices but cost and maintenance were the determining factors that led to the fiberglass decision. Since the major cost of fiberglass is in the model and mold making, the repetitive pieces of the cornice were cast relatively inexpensively. Areas that were not repetitive such as the oriels were less expensive to fabricate in wood. Repetition was the key to the lower cost of the fiberglass.²⁷

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CHAPTER 3 - COMPOSITION

GLASS

Fiberglass consists of a body of plastic reinforced with glass, with or without a surface coating called a gel coat. The glass fiber used is usually lime-alumina-borosilicate called "E" glass. "E" glass was originally designed for electrical applications, but was found to perform effectively for decorative and structural uses. It is known as the standard textile glass.¹ Other glasses that may appear in fiberglass production are: "S" glass -- a high tensile strength glass; "D" glass -- an improved dielectric glass used for high electronic performance; and "C" glass -- a chemical glass that provides greater resistance to acids than "E" glass.²

The glass used as reinforcement is manufactured into fibers from a raw glass batch. The fibers are produced by two basic processes yielding two end products -- continuous threads or staple fibers. Continuous filaments are mechanically drawn from molten glass into individual filaments of indefinite lengths. The staple fibers are produced by blowing air or steam at molten glass, generating individual fibers ranging from 8 to 15 inches in length. Both fiber types are considered an intermediate reinforcement product and are further developed into strands, yarns and cords by twisting and cabling.³

The strength of the finished GFRP object is directly related to the proportion of glass. The more glass the stronger the piece. The arrangement of the glass is just as important as the amount in determining the strength of the piece. There are three possible glass arrangements: all glass strands are parallel to each other (unidirectional); the glass strands are arranged perpendicular to each other (bidirectional); and, the strands are randomly arranged (pseudoisotropic).⁴

In the first case where all strands are parallel the strength is maximum in the filament direction but extremely weak in the other direction. The bidirectional arrangement has increased strength in two directions. However, strength in each direction is less than with the unidirectional arrangement. The random arrangement has increased strength in all directions equally but at a lower percent in any one direction than the other two cases.⁵

The glass fibers can be produced as roving, mats, fabrics or woven rovings, but are most commonly used in commercial production as chopped strands. Roving is a group of parallel strands of glass fiber which have been tightly gathered and wound onto a spool. Roving can be found as either continuous strand roving or spun strand roving. The continuous strand roving consists of a number of individual strands gathered and wound together. The spun strand roving is also a number of individual strands gathered together, however, in this case the strands are

looped back and forth upon themselves before they are twisted to create a bulkier roving. The reinforcing strength of roving is parrallel to the direction of the strands. Roving can be used in numerous fabrication processes such as preforming, pultrusion, and most commonly spray-up.⁶

Continuous rovings or strands can be chopped into short lengths. Chopped strands are available in many sizes for compatibility with design requirements. The amount, type and size have a major influence on the integrity of the strand and therefore the end product. Short strands allow for the molding of relatively thin walls. Longer strands are often mixed with shorter ones to increase the glass content in areas prone to impact and crazing. The random lay of the strands gives strength in all directions. Strands are usually sprayed by a gun along with liquid resin to build up reinforced plastic parts on a mold.⁷

"Glass fiber mat is a blanket of chopped or continuous strands laid down as a continuous thin flat sheet. The strands are evenly distributed in a random pattern and then held together by adhesive resinous binders, or mechanically bound by needling."⁸ The reinforcing ability of continuous strand mat and chopped strand mat is essentially the same, but they have different handling and molding characteristics. Continuous strand mat can be molded into more complicated shapes without tearing. The characteristics of reinforcing mats are influenced by both the glass content

and the binder holding them together.⁹

There are two kinds of binders -- a high solubility and a low solubility. The solubility determines how fast the binder will dissolve into the liquid resin portion of the end product. The high solubility binder is usually used in the hand lay-up process where it is important that the mat give to fit the countours of the end product. In the press molding processes it is important to use the low solubility binder to assure that the reinforcement does not slip during fabrication causing large portions of unreinforced resin. Glass fiber mat can also be used in bag molding, autoclave molding and various continuous impregnating processes.¹⁰

Woven fabric is a textile constructed of interwoven yarns. The yarn is an assemblage of fibers or strands that can range from one strand to a bundle of two or more strands twisted together. Glass fiber fabrics are produced by interweaving the yarns both crosswise and lengthwise on standard textile weaving looms. Nonwoven fabric is a flat sheet constructed of parallel strands, yarns, or rovings bound together by an occasional cross woven strand or an intermittent dot of resin. Woven roving is essentially a fabric that is woven of rovings rather than yarns. It is a thicker and heavier fabric most often used in the hand lay-up process for products requiring extra strength.¹¹

A good adhesion between the glass fiber reinforcing and the plastic/resin base is essential. This good ad-

hesion is dependent on the surface finish of the fiber as well as the content of the resin. Most reinforcing is surface treated with coupling agents designed to establish compatibility with specific resin compositions.¹² The coupling agent reacts with and bonds strongly to the glass fiber surface. As the glass fiber, surfaced with the coupling agent, will bond tightly to the resin base. When the coupling agent is added to the fiber during formation it is called sizing. When added after fabrication it is called finishing.¹³

RESIN

Polyester is the most common resin used in reinforced plastics. Because of its low cost and ease of dispensing pigments, polyester accounts for almost 85% of all fiber-glass. Other resins used include; epoxies, acrylics, phenolics, silicones, melamines, and polyesters modified with acrylics. ¹⁴

Polyester resins used for reinforced plastics are generally prepared by reacting unsaturated dibasic acids with dihydric alcohols and dissolving this mixture in a reactive monomer such as styrene. The proportion of styrene to resin is approximately one to two. Other dilutents are vinyl, toluene, methyl methacrylate, and diallyl phthalate. The entire amount of reactive monomer used becomes part of the cured resin structure during polymerization.¹⁵

The solution can be cured with heat or with a catalyst.

The degree of flexibility, hardness and toughness of the reinforced plastic end product greatly depends upon the chemical nature of the resin.¹⁶

The polyester resins used in glass fiber reinforced plastics are thermal setting. This means that the polyester resins set or harden in the presence of heat. If the temperature is too high the resin will react quickly. Conversely, if the temperature is too low the resin will take longer to react and may not completely gel. The resin curing time can be controlled with the use of additives such as catalysts, accelerators, and inhibitors.¹⁷

Often an inhibitor is added to a resin during the manufacturing process. This inhibitor serves as a preservative to prevent any premature gelation during storage. The inhibitor must be neutralized when the resin is used in order to obtain a full cure. It can easily be neutralized by the addition of a catalyst, heat or light. A catalyst, typically stable on its own, will break down into free radicals in the presence of heat or light. The free radicals emitted will react with the inhibitor until it is completely overcome at which point polymerization is initiated. The higher the temperature the faster the decomposition, the more free radicals and the faster the polymerization. Therefore the rate of gelation can be governed by regulating the energy source and the quantity of catalysts and inhibitors added.¹⁸

The rate of the resin set can also be affected by the

addition of an accelerator rather than heat or light. The accelerator or promoter will react with the catalyst just as heat would and initiate the curing process. Accelerators are most commonly used when the energy source is deficient or with complicated units where it is difficult to apply heat evenly. The most common accelerator used is a combination of cobalt naphthenate and hydroperoxide, however there are many accelerators available to match the needs of the situation.¹⁹

Many of the properties of the end product are dependent on the length of curing time. Two properties most affected are the average molecular weight and the viscosity. The quicker the cure the more points of unsaturation in the polyester molecules and the higher the molecular weight. Increased molecular weight allows for high tensile, flexural and impact strength of the cured resin. The corrosion resistance of a polyester against moderately concentrated acids, inorganic and organic salts and some alkalies is increased in rigid resins. Therefore, resins of increased molecular weight are more corrosion resistant than those of lower saturation. If the cure is slower allowing for a lower percentage of unsaturated acid the flexibility of the cured resin will be greater. Controlling the length of curing time allows for the desired properties to be achieved.¹⁹

Other variables that can affect the rate of resin setting and resin properties are; the age of the resin, the

batch to batch variations in the resin, the use of fillers or binders, the type of reinforcement, the mass to be cured, the size and type of mold, and the molding techniques.

Not all resins meet the design criteria. In fact it is sometimes necessary to combine resins to achieve the desired properties. Most often, blends are made to achieve desired toughness or impact resistance. The mixture of a rigid resin with a flexible resin can create a resin most appropriate for the given situation. Blending resins can also reduce the amount of warp during cooling, cracking or crazing.²⁰

Frequently, resins are diluted with styrene to reduce the viscosity of the resin. The styrene also; allows for greater use of fillers, helps alleviate trapped air, increases resistance to water in the finished product, and most importantly reduces costs. The disadvantage of the addition of styrene is that high concentrations reduce strength and cause crazing in resin rich areas.²¹

The gel coat present on many glass fiber reinforced plastic pieces is the exterior resin layer. It consists of an unreinforced resin coat containing fillers, such as pigments for color or aggregates for texture.²² Fillers are generally used with polyester resins to reduce costs. They are much less expensive than either resin or glass. Fillers also reduce shrinkage, reduce the tendency to craze or crack and help produce a smoother molded surface.²³

Most resins are sensitive to ultraviolet rays of the sun. After a relatively short period of exposure, pigmented resins tend to fade and yellow.²⁴ Certain ultraviolet absorbers can be added to increase the gel coat's resistance to ultraviolet light. These include anti-oxidants, photo-stabilizers and energy transfer agents. The addition of fillers can assist in shielding the resin from ultraviolet rays. However, if too much filler is used the particles will puncture the gel coat and increase deterioration. They can cause the gel coat to crumble, scale, powder or chalk.²⁵

The most common fillers are carbonates, talcs, clays and aluminas. The properties of the fillers must be considered when calculating the visual, mechanical and physical properties of the resin. Clays and talcs will cause a brown tint in pigments, especially when using pastels. Calcium and alumina have little affect on pigments but are abrasive and can effect the surface finish.²⁶

Most fillers cause a more rigid end product. Clays increase the flexural modulus. The absorbent qualities and particle size of the fillers will also affect the resin and ultimately the end product. Fillers with a high absorption will slow the resin flow and could cause the displacement of the reinforcing. Fillers of large sizes may not flow evenly through the reinforcing material causing them to cluster or clump.²⁷

If a gel coat is not used a surfacing veil or mat

should take its place. Without the gel coat the reinforcing material is only protected by a thin coat of resin. If the reinforcing material becomes exposed it can cause rapid deterioration. The surfacing veils or mats provide richer resin surfaces with finer textured reinforcing of glass or nylon. They prevent the underlying reinforcing from penetrating and hide any fiber pattern.²⁸

Fiberglass is combustible. It can, however, be made more fire resistant through the addition of flame retardants such as antimony oxide or hydrated alumina. The fire retardant chemicals will affect tensile strength, molding characteristics and possibly the color of the end product.²⁹ In addition, the additives that make fiberglass more fire resistant tend to negate the additives that make it resistant to ultraviolet rays. Therefore, flame retardants should be used in the body of the fiberglass while the ultraviolet absorbers should be included in the gel coat.³⁰

Each company has relatively compatible chemicals marketed under various brand names. It is difficult to differentiate the compositions of these chemicals. Therefore, care should be taken when reading the labels to insure the compatibility.³¹

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CHAPTER 4 - FABRICATION

There are many processes available to produce a fiberglass product with the desired appearance, performance and economics. Each process has its own advantages, disadvantages and capabilities. When designing a fiberglass unit production methods must be given consideration. The basic processes can be classified into two groups: open mold processes and closed mold processes.

The open molds are one piece molds. The piece can be either male or female (positive or negative). This allows for the formation of numerous molds and pieces at a reduced cost. The major characteristic of the molded end product is that only one side is finished (if pieces are to be finished all around two molds and an anchoring system must be used). Complex shapes and large objects can be formed. The open mold processes include; hand lay-up, vacuum bag, pressure bag, autoclave, filament winding, centrifugal casting, continuous pultrusion, and spray-up.¹

The closed molds processes involve two-piece molds. One is positive (male) and the other is negative (female). The molds are usually constructed of metal and are fairly expensive. The major characteristics of the molded end product are; highly polished or controlled surface finish, two faces finished, and clear reproduction of detail over and over and between parts. The closed mold processes

include; match-die molding, injection molding, and continuous laminating.²

OPEN MOLDS

Spray-up

The spray-up fabrication process is the most commonly used method for the production of nonstructural architectural elements and reproduction of ornament. Therefore, it is no surprise that the cornice at Georgetown, the Cornice at Landsdowne³ and parts of the Smythe Store Condominiums⁴ were fabricated by the spray-up method. The facade at the Smythe Store Condominiums was manufactured by a combination of processes including spray-up and hand lay-up. The spray-up method was developed to mechanize the hand lay-up method. Through this attempt various refinements and equipment were developed. The spray-up method provided a more efficient and less expensive method of production. With the introduction of the spray gun roving could be used instead of the more expensive fabrics. This fabrication method decreased time and labor, eliminated scrap materials, and could be performed by someone of little experience.⁵

The first step in any fabrication process is the mold. The mold material is determined by where, when, what and how detailed the original piece is. Simpler molds, such as the cornices at Georgetown and Landsdowne, are wood or

plaster. The more detailed molds are vinyl, silastic, polyester epoxy or rubber, or a combination. Molds that are cast on site, similar to the Smythe Store Condominiums, are generally a flexible material for easy application and removal. A brightly colored polyester resin is typically applied to aid in determining when the gel coat has completely covered the mold.⁶

Once the mold is set the gel coat is begun. There is no reinforcement in this coat. The gel coat is comprised of resin, pigment and ultraviolet (UV) catalysts. These chemicals are mixed in a cup and attached to a lid on the spray gun, becoming the resin supply in the system. The kind and percentage of fillers and exact catalysts of the case studies elements could not be identified. Records are not kept indicating exact constituents of each product.⁷

With the popularity of the spray-up method, many spray guns appeared on the market. The most common type of gun has a fiber roving cutter unit mounted on the side. The cutting unit can chop one to three strands of roving (which is many strands bound together) into desired short lengths. The gun can be set to determine the fiber lengths. The cutting unit works by an air motor that drives the cutting wheel. The wheel contains razor blades that rotate against a rubber pressure wheel. The force created by the speed of the cutting wheel sends chopped fibers out in a spray. The fiber spray is directed into a stream of resin which is released from a second nozzle. Therefore in this case the

glass fibers and resin are mixed externally in front of the nozzle tips. The combined stream carries the chopped fiber simultaneously depositing the fiber and resin on the mold.⁸

Some spray guns mix the fibers and resin internally. With the internal guns a separate supply hose of diluting solvent is fed into the gun to rinse the machine after the piece spray-up is complete. The difficulty of the internal mix guns are their tendency to clog. The external mixing machine is much easier to keep the passages unclogged. Success with internal guns is less likely for an amateur.⁹

Once the glass fiber and resin are in the mold work must be carried out fairly quickly. If the piece is not tooled right away the resin begins to set and is more difficult to work. The tools used are various size hand rollers and sticks. The sticks are used gently to make sure all detailing of the mold is packed solid with glass-resin mix. Care must be taken not to puncture the piece or scratch through to the gel coat.

Then the rollers are used to remove entrapped air. All areas of the mold must be carefully rolled. Any entrapped air will increase the chances for crazing and delamination. Surface air pockets allow water to wick up and freeze within the piece.¹⁰ All of these are detrimental to the life span of the piece. The piece is rolled until all air is removed, all fibers lay down flat and the surface is smooth.

Once the piece has begun to harden (so that it is not

tacky to touch), the edges are trimmed. This is done with a razor or exacto-knife. The piece should be trimmed back even with the edge of the mold. The edge of the mold is then wiped clean to avoid difficult cleaning of small hardened glass and plastic pieces. The cleaning of the mold edges also ensures that the gel coat will not be scratched when removing the piece.

The piece then cures at room temperature. Curing is an overnight process, although time varies. The workshops are above freezing but barely heated. The temperature usually remains below fifty in the winter. Therefore, in the winter the curing process takes much longer unless accelerators are added.¹¹

Once cured the piece is easily removed from the mold. The back of the piece is sanded to remove any loose glass and sharp edges.

The spray-up process is fairly simple, but leaves room for error. The first place error can occur is in the resin mix. Adding too much or too little of a catalyst can completely alter the properties of the final piece. It can also cause the piece to remain permanently soft. Measurements have to be carefully followed. The next and easiest place for error is during the spray process. The spray gun is difficult for an amateur to handle. Too much resin will produce a weak final product. Too little resin will clog the gun and leave glass edges exposed on the final piece. The exposed glass edges will lead to rapid deterioration.¹²

Error can also occur during tooling. These errors may not be obvious now but shorten the life span of the piece. The pieces that were not worked properly to eliminate air pockets will deform, delaminate and deteriorate. The pieces where glass fibers broke the gel coat will also deteriorate quickly.

Lack of skill or carelessness can cause damage to the surrounding area, injury to surrounding people or operator. Safety measures are important. Gloves should be worn when mixing the chemicals. The chemicals and glass pieces are not healthy to breathe. A mask should be worn while working. Full head gear is recommended while using the gun. If not, then a mask and eye goggles are essential. All spraying should be done in a vent box. These boxes are designed to shield the flying glass and ventilate the chemical fumes.¹³

Hand Lay-up

The hand lay-up is the oldest and simplest fiberglass fabrication process. The process was developed shortly after Dr. Leo H. Baekland discovered a usable resin.¹⁴ Although the spray-up method is the most popular, the hand lay-up is still used for complicated pieces requiring special surface attention or reinforcing. It is also prevalent for large scale pieces or seamless columns. The glass fiber, usually mat or fabric, is coated with resin and placed in the prepared mold. Hand rollers are used to

fill in voids and eliminate entrapped air. This process is repeated until the desired thickness is reached. The minimum thickness is usually 0.10 of an inch. The piece, however, can be built up to an inch or more and extra support cast in.¹⁵

Hand lay-up fiberglass can include a gel coat but does not have to. If a gel coat is used it is applied to the mold before the lay-up. The hand lay-up process usually cures at room temperature but heat or accelerators can be used. The exposed surface (when no gel coat is used), can be smoothed and polished.¹⁶

Vacuum Bag

The vacuum bag molding process is a refinement of the hand lay-up. A flexible plastic film, usually cellophane or nylon, is placed over the lay-up and sealed at the edges with a sealing compound. Then a vacuum is drawn across the film and the piece is cured. Here the vacuum instead of rollers eliminates the voids and forces out entrapped air or extra resin. This method allows for the molding of intricate pieces and complex shapes. This process is more expensive than the hand lay-up or spray-up but is more successful in eliminating air pockets.¹⁷

Pressure Bag

Pressure bag molding is virtually the same as the vacuum bag. The bag, usually rubber and preformed, is placed over the lay-up. Then air or steam pressure is used

to eliminate air bubbles and voids. An advancement of the pressure bag is the autoclave molding. The lay-up in the bag is placed in a steam autoclave. High pressure which can be controlled, removes entrapped air more efficiently than the other methods. The pressure also allows the formation of denser pieces.¹⁸

Filament Winding

Filament winding uses continuous reinforcement to increase the fiber strength. Roving or single strands are fed through a bath of resin and then wound on a specially designed metal spindle. Special machines wind the impregnated glass in a predesigned pattern. Once the desired thickness is reached the wound spindle can be cured at room temperature or with added heat.¹⁹

Centrifugal Casting

The centrifugal casting process is used to create round objects such as open end pipes and tubing or closed-end containers. In this process, chopped strand mat reinforcement is coated with resin and inserted into a hollow cylinder which is then rotated. Pressure forces the glass and resin against the walls. Once the desired shape and thickness is formed, the cylinder can be cured at room temperature or with added heat.²⁰

Continuous Pultrusion

The continuous pultrusion method is often used to create channel sections. Continuous strands or roving are

impregnated with resin and then pulled through a die which sets the shape and controls the resin content. The final stock is pulled through an oven to cure.²¹

CLOSED MOLDS

Match Die Molding

Match die molding is a fast and inexpensive production method for manufacturing fiberglass forms. A mat or fabric is combined with resin immediately before or after it is placed in the mold. Once the resin and reinforcing are in the mold the matched metal dies (one positive and one negative -- male and female), are put under a pressure of several hundred psi.²² These dies form and cure the fiberglass piece. The match die molding technique allows for a finished surface on both sides of the fiberglass unit.²³

Continuous Laminating

In continuous laminating, layers of fabric or mat are dipped in resin and stacked up between cellophane sheets. As the sheets are stacked squeegee rolls are used to control thickness, and, resin and air content. The finished pile is passed through heat to ensure bonding and then left to cool. This method is commonly used for manufacturing fiberglass panels.²⁴

Injection Molding

Injection molding is another high production process.

It is the fastest compression process. This fabrication technique was especially designed for use with thermoplastics. The glass and resin are put into a heating chamber to soften. The mixture, in a fluid state, is injected into a mold cavity consisting of an inner and outer mold. The fiberglass unit cools within the cavity in minutes.²⁵ This process is becoming more popular for stock decorative units. The injection method reproduces detail well and is less time consuming than the spray-up method. The process is simple and eliminates the need for skilled craftsmen. In addition, the injection process automatically removes entrapped air and limits the chance of delamination during aging.²⁶

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CHAPTER 5 - FIBERGLASS PERFORMANCE EVALUATION

How long will fiberglass last? Unfortunately, there is not a definite answer. The product is under sixty years old and has been constantly changing. There are chemicals that can be determined to increase the life span of fiberglass, however, because they are new the life expectancy can not be calculated. Just like any other material it will last longer if faultlessly fabricated, properly installed and well maintained.¹

There are five major causes of glass fiber reinforced plastic product failure: misapplication; poor design; outdated, damaged, or improper ratios of constituents; poor manufacturing; and weathering, either naturally or by neglect.² Misapplication most commonly occurs when the decision to use fiberglass is based solely on cost rather than considering all the required characteristics. As mentioned earlier, the fiberglass decision should take into account aspects of visual, physical and functional compatibility as well as the budget concerns of the owner or developer. There are many obvious examples of the misapplication of fiberglass in preservation, conservation and building construction in general.

The use of fiberglass for the cornice at Georgetown University Student Housing appears to be a misapplication. Judging on visual compatibility the cornice is an uncon-

vincing imitation of wood. The use of the gloss finish and pigment in the gel coat give the finished product a plastic look (see illustration 10). The pigments available to be used in the resin gel coat are somewhat limited and provide a uniform machine-made finish unlike that of wood.³ The cornice was made from a fabricated mold rather than cast from an original. This resulted in the cartoon appearance of the piece, since edges were too crisp and flat surfaces were too regular. The cornice was fabricated as one piece in even lengths for ease of installation. Unfortunately, this eliminated the definition of dentals and other cornice elements essential to the character of the wood cornice.

Since the project was not one of historical significance, nor was there existing wood cornice to match, it could be said that a visual match was not essential. However, since the original goal of the project was to emulate the wood cornices surrounding the project with lower cost,⁴ the project failed to live up to its ideals. In addition, the oriels fabricated in wood rather than fiberglass, are so delicate that the fiberglass appears all the more clumsy (see illustration 11).

Another situation that has often proved to be a misuse of fiberglass is in the replacement of terra cotta. Although the initial color match of fiberglass and glazed terra cotta is usually perfect, the weathering differences of the two materials will exhibit a poor match in the long run. In addition, it is presently next to impossible to

create a polychrome gel coat to match some of the more decoratively glazed terra cotta elements.⁵

In the case of unglazed terra cotta, the color of the fiberglass on a dry day may be a perfect match, however during a rain storm the color will no longer match. Fiberglass has been used for terra cotta replacement and improving technology allows for more color fast products. However, a fiberglass replacement for terra cotta will have to be replaced more often than terra cotta itself and therefore might prove to be more expensive in the long run.⁶

It is therefore obvious that the properties of fiberglass must be close to that of the original material. In the case of the Smythe Store Condominiums and the Lansdowne apartments, fiberglass appears to be a satisfactory replacement material. The properties of fiberglass are closer to that of metals than wood or clay products.⁷ Cast iron and pressed metal are most often painted, allowing for an even closer visual match of painted fiberglass.

Fiberglass, similar to most building products, will fail if not designed and installed properly. The design of the piece includes; thickness, reinforcing, additives, fillers, undercuts, holes for ventilation, joints, holes for screws and bolts, and surface finishes.⁸

The thickness of the glass fiber and resin body is determined by the size, shape and strength requirements of the piece. GFRP has a relatively good weight to strength

ratio when compared to most other materials but it is not a stiff or rigid material and is prone to creep. Larger pieces usually need wood members, plywood, or other stiffeners to deter deformation. Fiberglass must be restrained to avoid cracking, but joints must be designed to accommodate some movement for thermal expansion. When compared with other materials glass fiber reinforced plastic has a rather high coefficient of expansion (approximately 16.6×10^{-6} inches per degree fahrenheit). If joints are not designed to accommodate expansion the fiberglass may warp. Slotted joints work well to provide room for expansion and hold the piece in place.⁹

The cornice at Georgetown University was designed for proper ventilation and installation (see Appendix). In most cases the fiberglass fabricator will take no part in the detailing for installation of the piece. This presents a problem since architects/conservationists are often unfamiliar with the properties of fiberglass. Edon Corporation, however, usually takes control in designing the piece once given a profile from the designer.¹⁰ At Georgetown University they provided clearly documented shop drawings indicating the proper fabrication and installation of the cornice. They allowed for movement between pieces through caulk joints, and separated the fiberglass from movement of other building materials. A common aesthetic complaint is the obvious caulk or lap joint in fiberglass elements. This, however, is no more obtrusive than the caulk or lap

joints required in most materials that fiberglass emulates.

The Edon Corporation provided weep holes for ventilation. These holes or vents allow for condensation to escape from the void behind the fiberglass unit. These vents, when properly capped, are barely visible. Aesthetic problems are encountered when caps are missing. This is another of the visual problems at the Georgetown University Student Housing project, where there are numerous cornice vents that have lost their caps (see illustration 12). The fiberglass piece, just as any cornice, must be designed to shed water. Deterioration can be intensified if the piece puddles rather than sheds water.

The fiberglass elements at the Smythe Store Condominiums were designed to be installed just as the original cast iron would have been.¹¹ Thus far, there is no indication of anchoring problems. The columns were fabricated in two pieces and joined upon installation. The remaining facade pieces were anchored back to the underlying structure.¹² The Smythe Stores had an earlier problem with the rusting and separation of a bolt anchoring a piece of cast iron. The cast iron piece fell and a pedestrian was severely injured.¹³ The bolts anchoring the fiberglass must be protected from oxidation and rusting. They should also be checked for deterioration as part of the regular maintenance schedule. Fortunately, the rupturing of one bolt on a fiberglass unit would not provide great enough force to cause the other bolts to rip, and the piece to

fall. More likely the deteriorated bolt would blister or rip the resinous gel coat.¹⁴

At Lansdowne the cornice was installed just as the original metal cornice would have been attached. There are no vents to provide for the escape of condensation. Joley Company, the fiberglass fabricators, believe that the cracks between the cornice and the building face will allow for adequate ventilation, making the addition of vents unnecessary. Only time will tell the consequences of this elimination (see illustration 13).¹⁵

The third most common source of failure is inadequate control of the constituents. This means that the materials used in the production of the fiberglass product were faulty or inadequate. Quality control is essential. The quality of the constituent materials can greatly effect the outcome of the product. Out-dated resin will not cure properly, or may yellow as soon as it is exposed to light. It is essential that the additives to the resin and the resin's properties are studied and clearly recorded. There are many variables in the constituents of fiberglass and they must be carefully controlled to ensure reproducibility and uniformity. Often, resin blending is used to alter the properties of the resin. If these are not recorded then successes and failures cannot be noted.¹⁶

The fourth source of failure is poor fabrication. The production of fiberglass is not a "do it yourself" operation. There are too many variables to take it lightly.

The fabricator must have proper quality control over the constituents, production, and evaluation of the end products. Production failure can cause early weathering of the fiberglass component. There were no records kept of the exact additives used in the production of the case study components.¹⁷ It can be assumed that if failure occurs it will be nearly impossible to determine why. There is no way to insure that an exact replication of any of these pieces could be made. The Lansdowne apartments and the Georgetown University Student Housing have extra fiberglass units stored away to use for replacement, however, if those are damaged or insufficient, replications will have to be made. The molds were saved, but that only insures that the new piece will be formed identical to the last. It does not insure that the constituents and other variables in the fabrication process will be identical to the earlier pieces.¹⁸

The architect/conservationist should understand the nature of fiberglass fabrication and weathering, and take responsibility for the acceptance or rejection of the end product. Since most failure of fiberglass is due to pre-environmental conditions which occurred during design or fabrication, the architect/conservationist must carefully inspect the fiberglass component before acceptance.

Failure, as mentioned earlier, includes; improper cure, resin rich or resin poor areas, fiber misalignment, unbonds, inclusions, machining damage, impact damage,

fastener fretting and pull out, and environmental degradation. All the above forms of failure other than environmental degradation can be identified by non destructive inspection before installation.¹⁹

The architect/conservationist should check the contractor's facilities and inspect the raw ingredients. Facilities that keep outdated materials should be avoided. In addition, the architect/conservationist should inspect the manufacturing operations during various points of the production process.

Visual inspection is obviously the most accessible and manageable non-destructive test method (a complete GFRP test list is available from American Society for Testing of Materials). Therefore, it is the most extensively used. The architect/conservationist should look for wrinkles, air bubbles, pitting, blisters, dents, scratches, crazing, delaminations or inclusions of foreign matter. There should be no reinforcement voids or clumps, stains or discolorations. Pieces should be inspected under good light. It is preferable to check the fiberglass end products under natural light rather than artificial light. The use of a magnifying glass helps to identify small misfabrications.²⁰

The fifth major source of failure is weathering. Weathering can be caused by many factors; ultraviolet radiation, temperature, water, oxygen, micro-organisms, industrial gases and mechanical loading from wind and snow.

At this point the case studies are all weathering fairly well. The Georgetown University Student Housing project, however, is susceptible to far greater weathering conditions than the other two since it does not have the extra protection of a layer of paint.

The gel coat in an unpainted product is extremely important. It is virtually the only means of protection. It protects the body of the GFRP from the attacks of water, wind, soot, and especially ultra violet rays. If the gel coat is too thick, it can become brittle and/or crack. This most often occurs due to expansion and contraction of the unreinforced coat with thermal changes. If the gel coat is too thin the glass fibers will be exposed to the rain and swell causing the gel coat to craze.*¹ Repetition of this event will cause the gel coat to crack. Protruding fibers are frequently a cause of deterioration. They provide a deeply embedded place for the collection of soot and dirt. In addition, glass fibers once exposed can easily wick up moisture. The moisture once internal can cause rapid deterioration and especially delamination. This creates a very tenuous situation in that the proper balance is still questionable.*²

A deteriorated gel coat can be repaired. This is most commonly achieved by cleaning and sanding the surface to be repaired and then applying more pigmented resin. However, patches can be seen from a close viewing point. It is also important to remember that patches generally do not hold up

a well as the original undamaged piece.*³

Another disadvantage of an exposed gel coat is its sensitivity to the sun. Ultraviolet absorbers provide some shielding from the sun's rays, but are not perfect. Also, fillers used to achieve many visual and economic characteristics eliminate the effects of the ultraviolet absorbers and accentuate the fading of the color over time.*⁴ The resin rich gel coat, unpainted, is susceptible to ultraviolet degradation and yellowing. Gel coats that are matte and rich in pigment are more prone to chalking and powdering. *⁵

The painting of fiberglass is recommended. The paint coat adds an extra layer of protection and helps shield the gel coat and piece from the elements, especially ultraviolet rays. Other advantages of paint is that it offers a sacrifice layer that is less expensive and easier to repair. In addition, an accurate color match is difficult to achieve with pigmented resin coats. Paint eliminates the chance of error.*⁶

Often, problems occur with painted fiberglass that has a glossy gel coat below. The resin rich surface tends to bleed through the paint. Most painted surfaces, therefore, have a matte or textured gel coat.*⁷

For maximum durability of the fiberglass product a routine painting schedule should be followed. The painting schedule of the fiberglass at Smythe Stores and Lansdowne should follow the same schedule as the other metal ele-

ments. However, fiberglass must be painted with special primers compatible with the material. Paints for fiberglass must be specially chosen to achieve an adequate bond. All fiberglass surfaces must be pretreated in order to satisfactorily accept the paint. The key to a lasting paint job lies in the primer. Most fiberglass units are factory treated for ease in painting.²⁸ The painting is best done after installation. This avoids the chance of scratching and chipping during transport. In addition, painting on site eliminates possible color mismatch. For a good visual match the painted fiberglass should look as good or bad as the surrounding paint job.²⁹

The life span of the paint is dependent on the quality of the paint and the hostility of the environment. A quality paint job typically "looks good" for five to six years. Fiberglass repainting should be coordinated with the maintenance schedule of the other building components. In Charleston, a fairly corrosive environment, fiberglass fascia and cornice units are typically painted every five to six years. This is the same maintenance schedule as the stucco facades.³⁰ In Corning New York the Rockwell Museum cupola has needed repainting after two years. This is most likely the result of inadequate compatibility between the primer and the paint, accelerated by the hostile industrial environment.³¹

There are numerous successes and failures of fiberglass components. The first glass fiber reinforced plastic boat

is still functioning and remains in good condition. This boat has probably been well taken care of throughout its life. An example where fiberglass failed so radically that it had to be removed is the minarets installed in 1960 on Brighton Pavilion in England.³² The reasons for the minaret's deterioration were never determined. It could have been any combination of faulty fabrication, poor maintenance or problems with the resin mix chosen for the base.³³

The design and construction divisions at Disney Corporation are versed in the most progressive glass fiber reinforced plastic technology. Approximately 60-80% of Disneyland and Disney World are custom built of fiberglass. Since both amusement parks are situated in locations that are subject to severe sun the UV factor was of much concern to Disney. They conducted numerous studies and spent thousands of dollars on research. They found cleaning and painting to be the best protection for fiberglass. These amusement parks are constantly cleaned and are painted every three to five years. Both parks appear to be in good condition. It is obvious that considerable attention is given to their maintenance.³⁴

The smaller amusement parks where fiberglass can be seen in extreme deterioration do not have a regular maintenance plan for the fiberglass. The fiberglass is installed as a "maintenance free material". Once installed it is left until its removal after radical deterioration. Fiber-

glass needs to be repainted as often as metal. If not painted, the gel coat should be waxed on a similar schedule to painting.

NOTES TO CHAPTER 5

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CHAPTER 6 - A REALISTIC ALTERNATIVE

Before concluding, it is worth summarizing the benefits and disadvantages of glass fiber reinforced plastic to determine its appropriate applications in preservation and conservation work.

There are several advantages for the use of fiberglass. The molds can be cast on site for exact detail in the replications. From a distance fiberglass successfully imitates other materials. When painted, differentiation between fiberglass and other materials is virtually impossible even at close range. For example no one would know that the clock tower on Independence Hall in Philadelphia is fiberglass imitating wood.¹ The cornice at the Curtis Center in Philadelphia is also fiberglass, formed with fillers to look like stone.² It is relatively impossible to determine which of the five buildings at the Smythe Store Condominiums is fiberglass rather than cast iron. Finally at the Lansdowne, the end of the metal cornice and beginning of the fiberglass cornice is indeterminable to the untrained eye.

Another advantage is that fiberglass "is lightweight and has a high strength to weight ratio."³ Comparatively, it is strong, durable and resilient. It is also inexpensive to transport and erect because of its light weight. Methods of installation are quick and simple. "Fiber glass

reinforced plastics may be fabricated into almost any desired shape, with comparatively great savings in tooling costs. They also have the versatility of cutting down drastically on the number of components required for a given assembly."⁴ (see illustration 14).

As for cost, the constituents of fiberglass are most often less expensive than the constituents of the original materials. For fiberglass, the largest cost is accrued in making the mold. This cost, however, is a one time expense. The molds can be used again and again.⁵ Georgetown University Student Housing is an excellent example of how replication kept the costs down. Three molds were needed for the entire cornice. One mold was a ten foot length of cornice and the other two were right and left versions of the end brackets. The cost of making the pattern, since this was new rather than cast from an original, and the molds for the cornice piece alone was close to three thousand dollars. Since the cornice ran for a distance of over 1300 linear feet the total cost when divided over all the units was approximately twelve dollars per square foot (twenty-five dollars a linear foot). The Joley Company who produced the cornice at the Lansdowne Apartments estimated that the Georgetown cornice could be made at their factory for eight to ten dollars per square foot. It is difficult to determine the conditions which led to the Joley Company's lower estimate.⁶

Glass fiber reinforced plastic is mildew and rot resi-

stant and has proven to be durable when exposed to corrosive chemicals such as mild acids, salts and alkalis. It is durable to most environmental conditions, especially when painted. If properly tested most pre-environmental destructive conditions can be detected before acceptance of the product, therefore minimizing the weathering effects.⁷

Fiberglass does not undergo deformation until a temperature of 1200-1500 F. It has high tensile strength and good elasticity in comparison to other materials. It supports fairly large loads of snow and ice without losing its integrity or damaging surrounding building fabric.⁸

Finally, fillers and additives have been produced to allow fiberglass to be designed uniquely for each application. Numerous end products have been developed for specific project needs, such as greater temperature resistance, higher electrical properties, resistance to acid or alkali, greater tensile strength or mechanical stiffness, and absorption of harmful radiation such as x-rays.⁹

A disadvantage of fiberglass is that it is not very stiff and is prone to creep. It can, however, be reinforced. Fiberglass has a fairly high coefficient of expansion and contraction, and therefore must be designed with jointing that allows for movement. If poorly fabricated or left unmaintained it will deteriorate severely. Fiberglass is extremely sensitive to ultraviolet rays and pigments in the gel coat tend to fade and discolor more quickly than other material finishes. Since fiberglass is

non-porous the pigment in the gel coat does not change color when wet. It is therefore incompatible with porous materials that darken when moistened¹⁰.

The pigmented resin coats tend to deteriorate in appearance through tonal changes such as variegated, lighter or darker tones and streaking. An unpainted gel coat can be damaged by scraping, scuffing or natural weathering. This physical degradation causes an erosion of the surface texture, shape or visual definition. Deterioration advances rapidly once the fibers of the body are exposed.¹¹

In addition, an aesthetic match may be inderterminable when new, but fiberglass may weather differently than remaining building materials. These cases are a misapplication of fiberglass and can be an enormous problem. This is especially true when only a piece of ornament is replaced and the existing material and fiberglass are side by side. This is not problem when the fiberglass is painted.¹²

Lastly, there are cases were fiberglass cannot be used because of fire codes. Although fire retardant agents have been developed fiberglass is still relatively combustibile in comparison to other materials. There are cases where extensive use of fiberglass on the exterior of buildings may not be permitted due to building code regulations. These codes may require that the fiberglass be protected from the interior by special fire retardent layers or that sprinkler systems be provided.¹³ The degree of com-

bustibility has been improved in recent years by altering the resin type used and the glass fiber length and content.¹⁴

In conclusion, whether or not fiberglass is a realistic alternative depends on proper application, design constituents, fabrication and weathering conditions or maintenance requirements. It appears from the cases studied in this report that fiberglass works best in replication of cast or pressed metals (see illustrations 15 and 16). This can most likely be attributed to the similar characteristics of the two materials. The fabrication process of fiberglass and cast or pressed metals are fairly similar. The fabrication processes can often give insight into the nature of the materials.

The design, installation and physical and mechanical characteristics of fiberglass and metals are compatible. In addition the maintenance schedules of the two materials are relatively close and can easily be combined. The use of fiberglass to emulate metals eliminates the need for fillers to imitate textures or colors unnatural to the fiberglass. Since metals such as cast iron or pressed metal are usually painted, the fiberglass will be painted, insuring better durability.

Replication from a metal original is the simplest mold production process. Metals provide a non-absorbant positive from which the flexible or inflexible negative mold can be formed.

Fiberglass is not recommended to replicate terra cotta (glazed or unglazed), wood (unless indistinguishable from the ground) or stone. There are new products on the market such as glass fiber reinforced concrete which have proven to be more successful in the replication of stone elements.

John A. Fidler in his article on the use of glass fiber reinforced plastic facsimiles in London states:

...I am persuaded that the plastic reproduction of decorative detail usually only works well in situations where it is designed to match original materials which were themselves painted. In effect, that which is visible to the layman, in such circumstances, is merely the flat surface layer of paint, the substrate then being incidental.¹⁵

As this report verifies, John A. Fidler is accurate in his recommendation that fiberglass be used in situations where the original material was painted. His statement of its insignificance, however, seems a bit radical. Whether or not a substrate can be seen does not determine its importance. There are virtually no other building materials that can effectively and cost efficiently replace cast iron. Few materials have the potential to imitate the decorative complexity of historic cast iron and pressed metal.

The substrate has many important characteristics beyond the visual ones. As discussed earlier, substitute materials must be physically and mechanically compatible. It would be difficult to find any other substitute material that can be used in conjunction with these metals without

any chance of causing corrosion to the remaining historic fabric. In addition, substitute materials must provide a compatible maintenance schedule. Fiberglass as a replacement material for cast iron and pressed metal is successful on all of these accounts.

All building materials have appropriate and inappropriate applications and should be carefully analyzed before use, but should not be written off as insignificant without thorough consideration. There have been many successful fiberglass applications in building conservation and the potential of fiberglass continues to grow. The drawbacks in using fiberglass today could be solved by tomorrow. "The factors of cost, time, and new functional requirements continue to exert pressure for architects [conservationsits] to find better ways to build....The architect [conservationist] who adds plastics to his [her] vocabulary of design will have expanded his [her] capabilities in modern building technology."¹⁶ It is essential for conservationists to take advantage of and incorporate modern building technology into the field of preservation. It is not to say that fiberglass is the only solution to all preservation problems, but it should be considered as a realistic alternative.

NOTES TO CHAPTER 6

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Illustration 1. The Smythe Store Condominiums: Repetitive components cast iron and fiberglass.



Illustration 2. The Smythe Store Condominiums: Arch Street facade.



Illustration 3. The Lansdowne Apartments: Parkside Avenue facade.



Illustration 4. The Lansdowne Apartments: Original galvanized iron bay and fiberglass replication of decorative tower.



Illustration 5. The Lansdowne Apartments: Fiberglass replication of elaborate turret and cornice.



Illustration 6. Georgetown University Student Housing: 37th Street facade.



Illustration 7. Georgetown University Student Housing:
Detail of fiberglass cornice and brackets.



Illustration 8. The Smythe Store Condominiums: Original
structure and fiberglass infill.



Illustration 9. The Smythe Store Condominiums: Detail of fiberglass column and capital.



Illustration 10. Georgetown University Student Housing:
Cornice and end brackets on courtyard facade.



Illustration 11. Georgetown University Student Housing:
Fiberglass cornice and wood oriels.



Illustration 12. Georgetown University Student Housing: Cornice vents capped and uncapped.



Illustration 13. The Lansdowne Apartments: unvented cornice.



Illustration 14. The Smythe Store Condominiums: Fiberglass column fabricated in two pieces.



Illustration 15. The Lansdowne Apartments: Detail of fiberglass replacement unit for ornamental galvanized iron cornice.



Illustration 16. The Smythe Store Condominiums: Fiberglass replacement units for decorative cast iron dentils and key block.

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APPENDIX

Included in Appendix A are the shop drawings for the design and installation of the fiberglass cornice at the Georgetown University Student Housing project. (Courtesy of Edon Corporation, 1160 Easton Road, Horsham, Pa., 19044).



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